14

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TO the conscientious schoolmaster the contemplation of a dissertation on the nature of fatigue can hardly seem an unmixed joy; for the subject is one with which he is already practically and sadly familiar. I may say at once, however, that I have not come here to remind you too acutely of this aspect of your professional work, your sensations at the end of a busy day in the class room. I, too, have felt those sensations, and I know how dully depressing, to both mind and body, they may be. They must be reckoned with and eliminated in the reform of the school. Much is written on the fatigue of the school child, but the ideal school course will allow the teacher too to bring an unjaded spirit to his successive tasks. In his Utopia the teacher will have his playground, as the child now has his. My present task, however, is not to limit myself to a discussion of the fatigue that is incident to life in the schoolroom, but to present to you a study of a specific topic in physiology, and to try to show that it has broad biological bearings.

In popular usage the term fatigue is employed loosely, for while it signifies, in general, a depression of physiological activity, resulting strictly from previous activity, physiological depression is often called fatigue when it is not at all clear that previous activity is at the bottom of it. It does not, however, appear to me at present necessary to hold always to the strict significance of the word, since in a given case there are still too many unknown causative factors. Moreover, in the marvelously complex weft of the human organism, where the physical and the psychical are inextricably intermingled, illusion is so readily mistaken for reality, especially in the phenomenon now before us, as often to make the detection of a genuine fatigue well-nigh impossible.

Let me proceed at once to an analysis of the phenomenon of fatigue Every one is familiar with its sensations; but not every one realizes that the sensations are but signs of physical and chemical conditions permeating the whole body. Fatigue is a general physiological phenomenon; not only is the whole body subject to it, but every organ, tissue and cell of which the body is composed. Like other general physiological phenomena, its study may be best approached by considering its manifestations in the parts of the organism. I propose to

[1] An address delivered before the Section on Hygiene of the Connecticut State Teachers' Association, at New Haven and Hartford, October 22, 1909.

examine it first in the tissue of voluntary muscle, which affords certain advantages for study over other tissues, because of the ease of employing the graphic method and other physical, as well as chemical, methods.

If, shortly after the death of an animal, a single muscle, such as a muscle of a leg, be removed from the body, be attached to the usual muscle lever of the physiological laboratory, and be stimulated in the usual manner at regular intervals, beginning when the muscle is fresh and continuing until it is well fatigued, the graphic record of the

FIG. 1. Series of contractions of a frog's sartorius muscle, excised and stimulated at intervals of two and one half seconds. Each successive vertical line is the record of a single contraction. The contractions at first increase in extent, this stage constituting the treppe, and later decrease, this stage constituting fatigue.

series of resulting contractions presents a striking picture. Both the extent and the duration of the contractions may be affected. There appears early an increase in the extent of the contractions, which proceeds gradually to a maximum. This is shown in the graphic record as an increase in the height of the successive muscle curves (Fig. 1) and has been called, not inappropriately, the staircase, or *treppe*. The treppe signifies that in the early stages of muscular activity the working power of the muscle is progressively augmented—there is a temporary improvement in the power to work. This in turn means that what physiologists call the irritability of the muscle, or, in other words, its power of responding to a stimulus, has become greater; hence the same stimulus is followed by a greater contraction. A progressive improvement in the power to work in the early portion of a task, I may say, is not peculiar to muscle. We all must have noticed it in our own experience, with both physical and mental labor. It has also been demonstrated by laboratory methods in nerves, the central nervous system, and other animal and plant tissues; and it is probably a characteristic of all living substance. An analogous phenomenon is observed when living substance is put under the influence of certain drugs—a small quantity of alcohol, for example, often effects a temporary improvement in the individual's power of performing work.

Following the treppe, the muscle may perform maximal contractions for a considerable time; it is in its best working condition; its irritability is such that a given stimulus calls forth the greatest contraction of which it is capable. But sooner or later the contractions begin to diminish in extent; they sink to the level of the original amount and below it; the muscle becomes gradually weaker and weaker, until, with long-continued effort, it may finally cease altogether to lift the weight. This decrease in working power from the maximum characterizes the stage of fatigue proper. Decrease in working power may, in fact, be said to be the universal physical phenomenon of fatigue, whatever form of protoplasm we may be considering. Decrease in working power is accompanied by a decrease in irritability. The stimulus remaining the same, the work is diminished: but if the stimulus be increased in intensity, the protoplasm may again perform more work for a brief time. Sooner or later, however, all stimuli cease to be effective, and the living substance is then either exhausted or dead.

If, in our graphic record of muscular fatigue, we are employing a favorite subject of physiological study, the muscle of the frog, we observe another striking physical change. Early in the series, even before the treppe has reached its maximum, the duration of each contraction begins to increase, mainly by a slowing of the process of relaxation (Figs. 2 and 3). This may reach great proportions before exhaustion sets in. This slowing of relaxation appears to be wholly absent in the fatigue of warm-blooded, and presumably of human muscle (Fig. 4).

Fig. 2. Series of contractions of the frog's gastrocnemius muscle, excised and stimulated at intervals of two seconds. Every fiftieth contraction is recorded. The increase in the duration of the process of relaxation as fatigue proceeds is shown in the progressive lengthening of the descending limb of the curves.

The fatigue of muscle tissue is thus characterized by marked physical peculiarities. It is only natural to ask what are the causes of these.

Happily it is becoming the fashion in physiology, if only slowly and following long after, it is true, the usage of John Stuart Mill, to speak less of causes than of conditions. The cause of a phenomenon is the sum total of its conditions. All conditions are causes, and it is illogical to select one or two conditions and dignify them by the seemingly superior designation. In speaking of the causes of fatigue, as is often done, one usually means its chemical conditions; for within protoplasm, when in activity, there occur certain chemical or metabolic changes, with which the phenomenon of fatigue is closely associated. These chemical changes involve two general processes, namely, the consumption of certain existing substances which are essential to the activity of the protoplasm, and the production and accumulation within it of certain waste substances. Here again the muscle has yielded us our chief knowledge. Of the substances that are consumed in protoplasmic activity, we know most about two, oxygen and carbohydrate. For all aerobic tissues or organisms a continual supply of oxygen is essential to the continuance of working power—in fact, one way of bringing on the main phenomena of fatigue seems to be by eliminating oxygen. On the other hand, recent work suggests that one of the means of increasing working power or temporarily, at least, delaying its loss, is by artificially supplying oxygen to the body. It has been known for some time that with the usual conditions under which we live, the main source of the energy of muscles and probably of other organs is carbohydrate material, glycogen or its near

Fig. 3. Series of 550 contractions of a frog's gastrocnemius muscle, excised and stimulated at intervals of two seconds. Every contraction is recorded, except at the places indicated by the black bands, at each of which the records of fourteen contractions are omitted. The record of the first contraction is at the bottom of the figure: that of the last one at the top. Fatigue is shown in the progressive decrease in height and the increase in length of the curves.

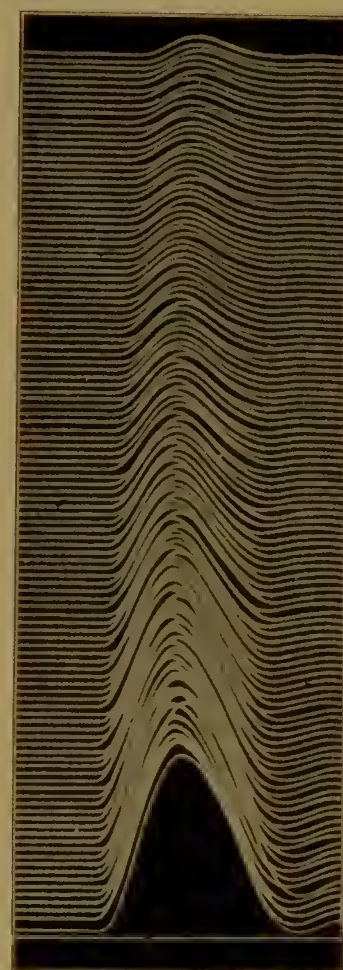

Fig. 4. Series of contractions of a rat's gastrocnemius muscle, excised and stimulated at intervals of two and one half seconds. Fatigue is shown in the progressive decrease in height of the curves.

relative, sugar. In the burning of carbohydrate in the tissues its potential energy becomes the actual energy of heat and muscle work. This fact would suggest the loss of carbohydrate as one of the factors in the oncoming of fatigue, especially in its later stages. Exact laboratory investigation, moreover, shows that if most of the carbohydrate be removed from an animal's body, he presents the symptoms of pronounced fatigue; and the same is true of his individual muscles, which are incapable of performing as many contractions as the muscles of a normal animal. Feeding such an animal with sugar restores his energy and makes his muscles capable of greater labor. This latter experiment has its counterpart in the common practise, by soldiers, guides and explorers, of consuming sweets, such as maple sugar, chocolate and raisins, when on long marches; while for the farmer in the hayfield nothing is more gratifying than a sweetened drink. It is quite possible that future research will discover other substances, besides oxygen and carbohydrate, the loss of which to the tissues is conducive to the production of fatigue.

Oxidation and destruction of carbohydrate result in the formation of at least two waste substances, both of an acid character, namely, carbon dioxide and lactic acid. Now it is an interesting fact, derived from laboratory investigation, that both of these substances, when in any but small quantity, are inimical to protoplasmic activity, and, furthermore, that a muscle under their influence shows the very same physical symptoms that are shown by a muscle fatigued through work. A fresh muscle to which has been given a moderate or considerable quantity of either one of these substances is a muscle already fatigued, although it may have performed no work (Fig. 5). These two metabolic products are thus believed to be important factors in the causation of fatigue, and to them has been given the name, "fatigue substances." Fatigue substances are poisonous, or toxic, to protoplasm; they diminish its irritability, so that a given stimulus calls out a less response than before. Certain other substances, besides carbon dioxide and lactic acid, are thought to belong to the class of fatigue substances, some of which are probably produced normally, while others occur only in diseased conditions. Among these pathological fatigue substances may be mentioned β-oxybutyric acid, which is present often in large quantities in a body suffering from diabetes—and it is a well-known fact that a person afflicted with diabetes is incapable of any considerable labor without extreme fatigue. β-oxybutyric acid occurs also in a starving body. The weakness of a person in starvation is associated

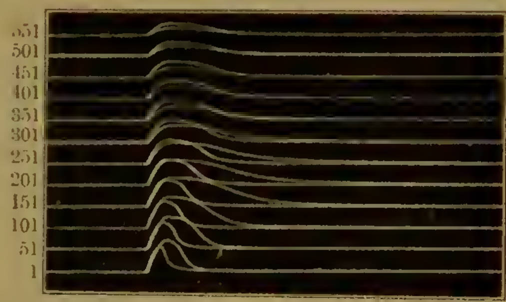

Fig. 5. Series of contractions of the two gastrocnemius muscles of a frog, excised and stimulated at intervals of two seconds; the one muscle normal, the other under the influence of carbon dioxide. The longer, or, in the later contractions, the lower curves are those of the poisoned muscle. Every fiftieth contraction of the two muscles is recorded from the same base line. The augmenting action of the fatigue substance is visible in the first two hundred contractions; its fatiguing action in the subsequent ones.

partly with the absence of the essential carbohydrate or other food stuff, and partly with the presence of β-oxybutyric acid. It is probable that future research will add still others to the class of fatigue substances, especially to those which are accompaniments of disease. Fatigue is one of the most common features of disease, and especially of diseases that are characterized by an upset of the chemical balance of the body. In such cases a considerable increase in the quantity of some intermediate metabolic product may conceivably lead to fatigue phenomena.

A few years ago, in studying experimentally the action of fatigue substances on muscle, I came upon an unexpected result. Fatigue substances in small quantity have a physiological action which is exactly the reverse of that of the same substances in larger quantity—instead of depressing or fatiguing protoplasm, they act so as to augment its activity. In other words, they increase its irritability, so that a given stimulus is capable of eliciting a greater response than it could elicit without the aid of the fatigue substances. Graphic records of the contractions of muscles under the influence of very small quantities of carbon dioxide, lactic acid or other fatigue substances, show how potent this augmenting action may be (Fig. 5). I believe that in this action we have the long-sought explanation of the treppe. In the early stages of muscular work the fatigue substances are present in small quantity, in later stages in large quantity. Correspondingly in the early stages there is augmentation or treppe; in the later stages there is depression or fatigue.

Thus far I have confined myself largely to a consideration of fatigue as exhibited by muscles, where the phenomena are best known and can be studied most accurately. There is every reason to believe, however, that the main principles of muscular fatigue are demonstrable in the other tissues and organs of the body—that in them also fatigue is characterized, physically, by a diminution in working power and, chemically, by both the destruction of energy-yielding substances and the appearance of toxic metabolic products. Diminution of working power is manifested in very different ways by diverse tissues. Glands in fatigue seem to secrete less than when fresh, and it may be that the action of digestive juices is diminished. The kidneys may be deranged, so that their epithelium is unable wholly to prevent the passage of albumin from the blood to the urine. A fatigued heart is dilated, its beats are quickened and may become irregular, and its diastole, or resting period, may become abbreviated. Fatigue often results in an abnormally high bodily temperature, constituting a fatigue fever. The chemical phenomena of fatigue in the various organs and tissues, apart from the muscles, is almost wholly unstudied, and there is great need of a careful analysis of the entire subject.

The fatigue of the nervous system is of great general interest, yet there are few subjects in experimental physiology that are more difficult of study. Notwithstanding that most of us doubtless believe that we know the symptoms of nervous fatigue well, physiologists have been able to discover only scraps of fact in this field. The isolated nerve of a cold-blooded animal, when artificially stimulated in the laboratory, can perform its work for many hours without showing the least sign of a diminution of power. Only when placed under unfavorable conditions, such as in light anesthesia, or when deprived of oxygen, does the nerve exhibit with continued stimulation a gradual loss of conductivity. From this it is inferred that the nerve fiber itself under normal circumstances is highly resistant to fatigue, and that any unfavorable dissimilative changes which it undergoes in activity are compensated for at once by an equal assimilation. This highly interesting and suggestive conclusion is perhaps equally true of nerve centers. Hodge and others, it is true, have demonstrated morphological changes in nerve cells as the result of artificial stimulation and of normal daily activity. Thus the nuclei of the brain cells of a honey bee may show a diminution in volume of 75 per cent., at the end of a day's labor; and the English sparrow, though popularly regarded as less typical of industry, reveals almost as much cerebral activity. Notwithstanding these evidences of metabolism, no one has yet succeeded in obtaining, by direct or reflex artificial stimulation of the nerve ganglia, the spinal cord or the brain of animals, indisputable physiological evidence of the genuine fatigue of the nerve structures involved. Many attempts have been made to detect fatigue in the nervous system by testing the muscular power, as by the employment of the ergograph, the instrument in which a muscle or set of muscles is made to perform a series of voluntary contractions and lift a given weight, the progress of fatigue being indicated by the rate at which the lift diminishes. But endeavors to arrive at an exact analysis of the result of such an apparently simple experiment have given rise to a controversy as to the location of the fatigue, some investigators claiming it for the muscles, others for the brain.

A still further attempt at the investigation of brain fatigue is through the study of certain mental processes during or following long-continued effort. Mental fatigue is characterized by a diminution of attention, a difficulty in concentrating one's thoughts, slowness in reacting to sensory stimuli, in memorizing or in reasoning, difficulty in recalling memorized passages, errors or slowness in mathematical calculations, and other phenomena. While these are obvious in the fatigued individual, all attempts at exact measurement of them and the deduction therefrom of the degree of psychical or physical fatigue have failed.

Thus, while some of the characteristics of nervous fatigue are known, all methods heretofore adopted to study the fatigue of the central nervous system exactly with a view of determining its relative susceptibility to fatigue are unsatisfactory. The preponderance of evidence at present seems to me to be in favor of a high degree of resistance to fatigue on the part of the brain and spinal cord, as of the nerve fiber itself. In fact, such a condition is what we should expect *a priori*. The nervous system is the administrative instrument of the individual; it directs, controls and harmonizes the work of the parts of the organic machine, and gives unity to the whole. It is not the frail, delicate thing, easily put out of gear, that we at times believe it to be. It is capable of enormous demands on its powers and of enormous resistance. It is the last system to succumb in many diseases and in such a dire condition as starvation. It would seem to be only highly advantageous to the organism that its nervous system should be able to resist the oncoming of fatigue, with all the direful consequences that might follow its advent.

After thus analyzing the phenomena of fatigue in their manifestations in the various organs and tissues of a complex body, let us briefly consider fatigue as we feel it in ourselves. When we perform a long-continued and ultimately fatiguing task, either physical or mental, we can recognize, with little difficulty, three successive stages of working power, although these are not sharply separated from one another. During the first stage our working power gradually increases; during the second it remains approximately stationary at a high level; during the third it gradually decreases. During the first stage our performance is at first distinctly up-hill work; we find it difficult to concentrate our attention; we feel already fatigued; we could easily give up and do no more. But, surprisingly enough, if we keep on we find the work getting easier; we can accomplish more and more, seemingly without greater effort; we seem to be breaking through barriers that have hindered us; our sensations are agreeable; we say that we are getting our second wind; we feel new courage and no longer care to give up. Before we realize it we have gotten our second wind and have passed into the second stage; our working power is at its best, and we continue to labor, heedless of time; if we attempt to philosophize, we are only conscious of the fact that our labor is easy and our burden light. But this stage, though it may be long continued, ultimately gives place to the third stage when we realize that our powers, after all, are limited, that work is hard, that either we must put forth greater efforts or our output diminishes, and that we are really tired. Now these three stages of individual labor are but the three stages which we have already seen epitomized in the isolated muscle—the treppe, the period of maximum contractions, and the fatigue—and I do not doubt that they are associated with the same chemical phenomena. The stage of getting our second wind is when our fatigue substances are in minute quantity, and they gradually augment our physiological irritability and our output of energy. The stage of our best work is when irritability is at its highest, we have a store of oxidizable fuel, and toxic products have not yet begun to exert their deleterious action. The stage of fatigue is when our fuel is becoming exhausted, its waste products are clogging the furnaces, and physiological irritability is low.

Fatigue, as we feel it after excessive work, is often spoken of as a sensation. Really it is a great complex of sensations. These sensations differ in some degree according to the character of the work, whether it is mental or physical, and if physical, according to the particular groups of muscles employed. But in extreme fatigue such differences are comparatively slight. There may be a "tired" feeling in the head of obscure origin; pain and soreness in the muscles, resulting from an excessive accumulation of blood or lymph, or perhaps from an actual rupture of muscle fibers; stiffness in the joints, resulting from lymph accumulation; swelling of hands and feet, from the same cause; sleepiness, which is accompanied by cerebral anemia; even a feverish temperature because of derangement of the temperature-regulating mechanism; and many other sensations, but, most general of all, a disinclination to perform either mental or physical labor, which may be due in part to general depression of the nervous system, in part to the presence of the unusual sensations, and in part to the mental recognition of the fact that the irritability of our tissues has become diminished and a greater stimulus than before is now required to induce a given action. It is not often possible for the individual to make a satisfactory analysis of the excessively complicated compound of sensations, which he may possess when his body is in a fatigued state. But it has come now to be generally accepted that the sensations

FIG. 6. Series of contractions of the flexor muscles of a human finger. The muscle was stimulated electrically every two seconds, and the resulting contractions were therefore involuntary. Record 1 was made when the muscle was fresh; record 2 immediately after three and one half hours had been spent in the oral examination of students; record 3 two hours after the completion of the examination. (From Mosso's "Fatigue.")

of fatigue result largely from events happening outside of the brain and spinal cord, events of which I have been speaking under the head of physical and chemical phenomena. Such events are not, however, confined to the particular tissues that have performed the fatiguing work, for fatigue substances, though produced in one tissue and fatiguing it, may be carried by the blood to others and there also exert their characteristic action. This fact, that the excessive work of one tissue may cause the fatigue of other tissues, is of great practical importance to us in our daily life. We all believe that excessive muscular work may cause mental weariness. It has been shown by laboratory experimentation that the reverse is true, that excessive mental work may cause muscular weariness. In an experiment upon himself Dr. Maggiora, of Turin, found that the flexor muscles of his middle finger, upon being stimulated by an electric current applied directly to them, were capable of lifting a certain weight fifty-three times before temporary exhaustion set in (Fig. 6). Soon after the completion of the test he entered the class room and devoted the subsequent three and one half hours to the oral examination of students, a task which, he being then a teacher of little experience, was excessively difficult. Immediately after the end of the examination he tested his lifting power again and found his muscles capable of making only twelve contractions. It is often thought that the best means of recuperating after a day's hard mental labor is through the performance of physical exercise. A temporary change of occupation may, indeed, be of great benefit, by relieving an exhausted organ and an exhausted focus of attention. But physiology tells us that a tired brain means a tired body, and that with the brain fagged there is nothing culpable in a desire for not only mental but physical rest.

But there is another aspect of personal fatigue which we can not neglect. Our sensations become our servants or our masters, according as we will. Either we control them, or they control us. Is it legitimate, is it moral, to yield to every sign of weariness? Here we meet at once the problem of the formation of habits. Fatigue may easily become with us a habit, a habit which is destructive to legitimate effort. We have all known the perpetually tired man, the chronically fatigued, to whom both initiative and performance alike are distasteful and to be avoided, when possible. This condition may at times be so pronounced as to be positively pathological, demanding special curative treatment. Fortunately such a condition is rare. Most of us may live on a high or a low plane of activity at will; we may do much or little; we may yield early to fatigue or we may successfully resist it for a time with impunity.

The more one studies physiology the more one appreciates the fact that protoplasm possesses an enormous power of work, and that the human body is endowed with marvelous capacity. Whether we shall get our second wind, or, having gotten it, whether we shall utilize to the full our powers of work, is a matter of our own will. I believe that few of us live up to our opportunities for accomplishing things. We are too inclined to yield to the early demands of fatigue. Even without exceptional hereditary endowment more of us might have, if we would, the endurance of a Weston, the discernment of a Darwin, the shrewdness of a Harriman, the determination of a Peary, or the insatiate desire to be on top which distinguished our late president. In his very sensible and characteristically delightful essay on "The Energies of Men," William James says:

> The human individual lives usually far within his limits; he possesses powers of various sorts which he habitually fails to use. He energizes below his *maximum*, and he behaves below his *optimum*. In elementary faculty, in coordination, in power of *inhibition* and control, in every conceivable way, his life is contracted like the field of vision of an hysteric subject—but with less excuse, for the poor hysteric is diseased, while in the rest of us it is only an inveterate *habit*—the habit of inferiority to our full self—that is bad. . . . We live subject to arrest by degrees of fatigue which we have come only from habit to obey. Most of us may learn to push the barriers farther off, and to live in perfect comfort on much higher levels of power.

Herein lies the value of training. Training, whether of the child or the adult, the athlete or the thinker, consists largely in the development of a power of resistance to the toxic fatigue substances, and is not unlike the production of a condition of tolerance to a poisonous drug by the administration of successively increasing doses of it. Physical training is not fundamentally different from general educational training. Habits of industry, which every educational system strives to develop in the child, are the converse of habits of fatigue, and in the last analysis habits of industry mean, in very large part, an acquired power of resistance to fatigue substances.

One difficulty which we all recognize is that of distinguishing between real and pseudo-fatigue in ourselves or others, and knowing when a rational degree of real fatigue has been reached. The matter is a vital one to teachers, for a knowledge of the rate at which working power diminishes, of the presence or absence of a fatigue state at a given moment, might be of material help in directing the pupil's work. Various studies have been made of the fatigue of school children, but the results of all of them are unsatisfactory because of the lack of a satisfactory method of investigation. Even the physiologist in his laboratory, however exact he may be with the muscles of animals, has no method of measuring accurately the degree of fatigue in the intact body of a human being. Our sensations are not altogether a safe guide. We often interpret a temporary sleepiness, a temporary lack of power of attention, and uneasiness to be free from our task, as signs of real weariness and evidence that we should stop our labors. Yet we know that often a slight change of conditions will seem to give us renewed energy, the feeling of fatigue is gone and we turn with freshness to our task; our supposed fatigue was only an illusion. Even with our imperfect experimental methods, however, enough has been discovered to show, among other things, that human beings differ greatly in the rate at which fatigue develops. Mosso demonstrated this many years ago, though his methods are not now regarded as the best.

I have thus far confined myself to a consideration of the nature of fatigue and the conditions under which it develops. Recovery from fatigue is perhaps of even greater interest. Both in the isolated muscle and in the intact organism, fatigue may be carried so far that recovery is difficult or even impossible. The later stages of fatigue are often spoken of as exhaustion, but obviously no sharp line can be drawn between fatigue and exhaustion. Exhaustion is probably most common when labor is continued for years without adequate resting periods. Exhaustion from a temporary effort is of rare occurrence, observable occasionally in athletes and in persons upon whom there is made a sudden and unexpected demand for enormous physical or mental exertion. Usually, however, when a fatiguing expenditure of energy by a living tissue ceases, recovery begins at once. Even in the excised muscle, with all supply of blood cut off, a few minutes' rest allows for a certain degree of recuperation, due possibly to the absorption of oxygen. If a weak solution of common salt, or, better, a suitable mixture of various salts, be passed through the blood vessels of the muscle for a few minutes and thus the accumulated fatigue substances be, at least partially, washed out, the recuperation is greater. If a small quantity of glucose be added to the solution, or if nutritive oxygenated blood be introduced, there is still greater recovery, and the power of further work is much enhanced (Fig. 7). All of these methods are

Fig. 7. Series of contractions of a frog's gastrocnemius muscle *in situ* and stimulated at intervals of two seconds. The flow of blood through the muscle was stopped by ligating the artery, and the record of fatigue was made. At the break in the series, the muscle rested five minutes, during which time the ligature was removed and the blood was allowed to circulate through the muscle. The record of contractions at the right of the break was made immediately after the resting period, and while the blood was still circulating.

physiological—in them the chemical conditions conducing to fatigue are replaced by reverse conditions and the result is reversed—oxygen and food are introduced, carbon dioxide and lactic acid are removed, and there is a restoration of working power. In the living human body the same processes and the same result are best brought about through the combined agencies of food and rest, with sleep. Sleep is here of value since, by its complete inhibition of the more obvious corporeal activities, it makes rest more complete and thus allows the more complete elimination of fatigue substances and restoration of those things that are essential to future activity.

Equally difficult with the problem of the extent to which labor may safely be carried is the problem of how much food, rest and sleep are required for healthful recuperation. How much we think we require is another question, for here again our sensations are misleading and it is easy to acquire habits which bear little relation to nature's demands. We here assembled, being in the shadow of Professor Chittenden's laboratory, are in the very center of the low-protein camp, and with appetites bridled we can safely defy those who tell us to eat what we please, when we please, and all that we please. There is, indeed, little doubt of the correctness of the main contention of Chittenden, Fletcher, Fisher and their followers, that it is physiologically advantageous to consume less protein than most of the civilized races consume, and it is impossible to avoid a strong suspicion that the presence of a superfluity of food stuffs within the body leads to an accumulation of intermediate metabolic products which in themselves act on the tissues as fatigue substances. The physiological optimum in the matter of quantity of food probably differs with each individual and, with our customarily unscientific habits of judging ourselves, is probably rarely known. This is equally true of the amount of rest and sleep required for recuperation. Our fathers told us "eight hours' work, eight hours' rest and eight hours' sleep"—yet did our fathers, more than we, literally observe the adage? As I believe that most of us eat too much, so I believe that most of us work too briefly and rest too long. Yet more significant than duration is intensity. "Work when we work, and play when we play," is not a meaningless nursery jingle, but a wise physiological dictum. Application, concentration, putting our whole selves into our task, with a wholesome disregard of fancied fatigue—that is the method of accomplishment. But when fatigue really comes, then should the task be laid completely aside for restoration. Play is one of the surest agencies for mental relaxation in the waking state. Pathetic was the confession of one of the world's most busy workers a few years before his death, at the age of forty-five, that he had "almost forgotten how to play." Effective sleep should be dreamless, and if it is of the right sort, it need not occupy one third of all our life. For most persons eight hours of actual sleep would mean nine hours in bed—and only a sluggard would demand that.

Food, rest, play and sleep may be regarded as the effective physiological antidotes to fatigue. One ingenious German investigator would add to these another. In an experimental study he believes that he has demonstrated in fatigued animals the existence of a fatigue toxin, different from simple carbon dioxide and lactic acid and allied to the toxins produced by bacteria. He claims to have extracted this in a pure form, and upon successive injections of it for a period of time into the bodies of other animals their tissues have produced, he claims, an antidote to it in the form of a real antitoxin. This antitoxin of fatigue, if administered to fatigued animals or even human beings, is said to bring about prompt recovery; if administered to fresh organisms it is said to greatly prolong their working period. I am not prepared to deny the truth of these claims, but such striking discoveries should be confirmed by other investigators before one can fully believe in their reality. It may be said that present science knows no safe, quickly acting, effective antidote to the toxic action of fatigue substances. There can be no doubt, however, about the temporary anti-fatiguing power of certain drugs. The caffeine of coffee and tea is one of these, and the theobromine of cocoa is another. Alcohol, too, may act as a temporary whip. When administered to even an isolated muscle, in small quantity, it augments activity, quickens contraction and delays fatigue; in large quantity it is depressing and hastens fatigue. In these respects alcohol is not unlike the physiological fatigue substances. It is undoubtedly useful in very brief emergencies involving fatiguing effort, but like other drugs its usefulness lies outside the normal physiological life of the individual.

Besides the more purely physiological and psychological aspects of fatigue, it has an important relation to many sociological problems. In its milder form it may be regarded as a blessing, since it leads to healthy rest. But if its warnings are not heeded, it may prove a serious affliction. By reason of its inhibition of activity it is a potent sociological force. It is one of the causes of misery and poverty and disease; it is an inciter of crime; it has helped to lose battles; it has limited industrial expansion. Professor Irving Fisher has recently estimated the minimum annual cost of serious illness in this country as one and a half billion dollars, and says: "The economic waste from undue fatigue is probably much greater than the waste from serious illness." Fatigue must be reckoned with in all human activities, and its toll must be rigidly paid. Happy is he who has the power so to direct his bodily machine as to obtain from it its highest efficiency.